2025

# AP® Physics C: Electricity and Magnetism

## Sample Student Responses and Scoring Commentary

**Inside:**

**Free-Response Question 1**

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

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## Question 1: Mathematical Routines (MR) — 10 points

**A (i)**

For a multistep derivation that includes the equation $\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}$ — **Point A1**

**Scoring Note:** Vector notation is not required for this point to be earned.

For a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$ (e.g., $2\pi r\ell$) — **Point A2**

For a correct expression for the enclosed charge (e.g., $\sigma_1\left(2\pi R_1\ell\right)$) — **Point A3**

**Example Response**

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}$$

$$E\left(2\pi r\ell\right) = \frac{\sigma_1\left(2\pi R_1\ell\right)}{\varepsilon_0}$$

$$E = \frac{\sigma_1 R_1}{\varepsilon_0 r}$$

**(ii)**

For substituting the expression for $E$ from part A (i) into $\Delta V = -\int_a^b \vec{E} \cdot d\vec{r}$ — **Point A4**

**Scoring Notes:**

- Vector notation is not required for this point to be earned.
- The sign of $\Delta V$ is not considered for this point to be earned.

For an attempt to solve the integral for $|\Delta V|$ that includes correct limits (e.g., $|\Delta V| = \frac{\sigma_1 R_1}{\varepsilon_0}\int_{R_1}^{R_2} \frac{1}{r} dr$) — **Point A5**

**Scoring Note:** This point may be earned regardless of the order of the limits of integration; for example, $\frac{\sigma_1 R_1}{\varepsilon_0}\int_{R_2}^{R_1} \frac{1}{r} dr$.

**Example Response**

$$|\Delta V| = \left|-\int_a^b \vec{E} \cdot d\vec{r}\right|$$

$$|\Delta V| = \int_{R_1}^{R_2} \frac{\sigma_1 R_1}{r\varepsilon_0} dr = \frac{\sigma_1 R_1}{\varepsilon_0}\int_{R_1}^{R_2} \frac{1}{r} dr$$

$$|\Delta V| = \frac{\sigma_1 R_1}{\varepsilon_0} \ln\left(r\right)\Big|_{R_1}^{R_2} = \frac{\sigma_1 R_1}{\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)$$

**(iii)**

For sketching a graph that is zero for both $0 < r < R_1$ and $r > R_2$ — **Point A6**

For sketching a graph that is decreasing and concave up for $R_1 < r < R_2$ — **Point A7**

**Scoring Note:** The curve does not have to intersect the vertical dashed lines for this point to be earned.

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**Example Response**

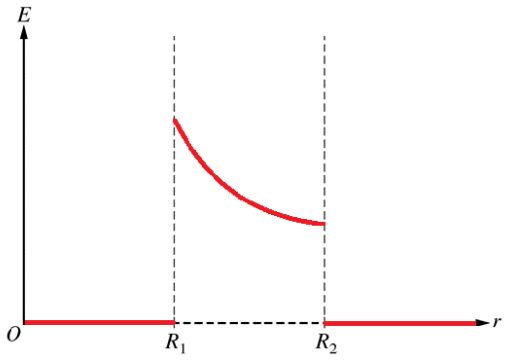


Figure 2

| | | |
|---|---|---|
| **B** | For a multistep derivation that includes the equation $C = \frac{Q}{\Delta V}$ | **Point B1** |
| | For indicating that $C$ with the dielectric material inserted is $C$ without the dielectric material inserted multiplied by $\kappa$ (e.g., $C = \kappa \frac{Q}{\Delta V}$) | **Point B2** |
| | For substitutions of both the total charge $Q$ and the potential difference $\Delta V$ that are consistent with part A | **Point B3** |

**Example Response**

*Without the dielectric material*

$$C = \frac{Q}{\Delta V}$$

$$C = \frac{\sigma_1 \left(2\pi L R_1\right)}{\left(\frac{\sigma_1 R_1}{\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)\right)}$$

$$C = \frac{2\pi L \varepsilon_0}{\ln\left(\frac{R_2}{R_1}\right)}$$

*With the dielectric material*

$$C = \kappa \frac{Q}{\Delta V}$$

$$C = \frac{2\pi L \kappa \varepsilon_0}{\ln\left(\frac{R_2}{R_1}\right)}$$

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## Question 1: Version J

**PART A**

i $\Phi_E = \int \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$

$E \cdot 2\pi r L = \frac{q_{enc}}{\varepsilon_0}$

$q_{enc} = \sigma_1 V$

$q_{enc} = \sigma_1 \pi R_1^2 L$

$E = \frac{q_{enc}}{\varepsilon_0 2\pi r L}$

$E = \frac{\sigma_1 \pi R_1^2 L}{\varepsilon_0 2\pi r L}$

$$\boxed{E = \frac{\sigma_1 R_1^2}{2\varepsilon_0 r}}$$

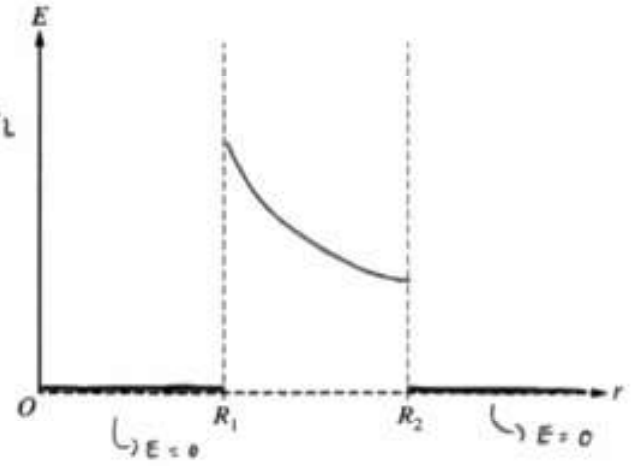


Figure 2

ii. $|\Delta V| = \int_{R_1}^{R_2} E\, dr$

$= \int_{R_1}^{R_2} \frac{\sigma_1 R_1^2}{2\varepsilon_0 r}\, dr$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} \cdot \int_{R_1}^{R_2} \frac{1}{r}\, dr$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} \cdot \ln\frac{R_2}{R_1}$

$$\boxed{|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln\frac{R_2}{R_1}}$$

**PART B**

$C = \frac{Q}{\Delta V}$ $\quad Q = \sigma_1 \pi R_1^2 L$

$C = \frac{KQ}{\Delta V}$

$C = \frac{K \cdot \sigma_1 \pi R_1^2 L}{\frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln\frac{R_2}{R_1}} = \frac{K \sigma_1 \pi R_1^2 L}{\ln\frac{R_2}{R_1}} \cdot \frac{2\varepsilon_0}{\sigma_1 R_1^2}$

$$C = \frac{K\, 2\pi L \varepsilon_0}{\ln\frac{R_2}{R_1}}$$



Go to Question 2 in Bluebook when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

## Question 1: Version J

**PART A**

i.) $\oint E \cdot dA = \frac{Q_{en}}{\varepsilon_0}$

$E \oint dA = \frac{Q_{en}}{\varepsilon_0}$

$E(2\pi rL) = \frac{\sigma_1 \pi R_1^2 L}{\varepsilon_0 L}$

$E = \frac{\sigma_1 \pi R_1^2 L}{2\pi r L \varepsilon_0} = \boxed{\frac{\sigma_1 R_1^2}{2r\varepsilon_0}}$

$\sigma_1 = \frac{Q_{en}}{A}$

$\sigma_1 = \frac{Q_{en}}{\pi (R_1)^2 L}$

$Q_{en} = \sigma_1 (\pi R_1^2 L)$

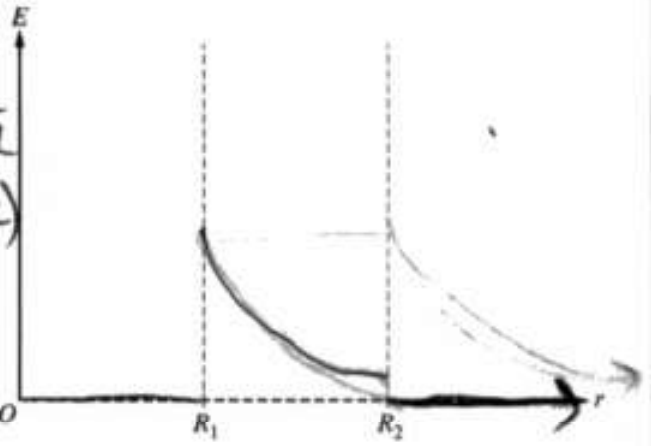


Figure 2

ii.) $\Delta V = -\int E \cdot dr$

$|\Delta V| = \int_{R_1}^{R_2} \frac{\sigma_1 R_1^2}{2r\varepsilon_0} dr$

$|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \int \frac{1}{r} dr$

$|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} [\ln(r)]_{R_1}^{R_2}$

$|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} (\ln(R_2) - \ln(R_1))$

$\boxed{|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)}$

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**PART B**

$C = \frac{K\varepsilon_0 A}{d}$

$d = R_2 - R_1$

$C = \frac{K\varepsilon_0 A}{R_2 - R_1}$

$A_+ = \pi R_1^2 L$

$A_- = \pi R_2^2 L$

$A_{Total} = \pi R_2^2 L + \pi R_1^2 L$

$A_{Total} = \pi L (R_2^2 + R_1^2)$

$\boxed{C = \frac{K\varepsilon_0 \pi L (R_2^2 + R_1^2)}{R_2 - R_1}}$



Go to Question 2 in Bluebook when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

## Question 1: Version J

$\sigma = \frac{Q}{A}$ $Q = \sigma A$

**PART A**

i) $\oint E\,dA = \frac{q_{enc}}{\varepsilon_0}$ $A = \pi(R_2^2 - R_1^2)$

$E(2\pi r) = \frac{\sigma \pi (R_2^2 - R_1^2)}{\varepsilon_0}$

$E = \frac{\sigma \pi (R_2^2 - R_1^2)}{2\pi r \varepsilon_0} = \frac{\sigma (R_2^2 - R_1^2)}{2 r \varepsilon_0}$

ii) $|\Delta V| = \left| -\int_{R_1}^{R_2} E\,dr \right|$

$|\Delta V| = +\int_{R_1}^{R_2} \frac{\sigma R_1^2}{2 r \varepsilon_0}\,dr$

$= \frac{\sigma R_1^2}{2\varepsilon_0} \int_{R_1}^{R_2} \frac{1}{r}\,dr$

$= \frac{\sigma R_1^2}{2\varepsilon_0} \left[\ln|r|\right]_{R_1}^{R_2}$

$= \frac{\sigma R_1^2}{2\varepsilon_0} (\ln(R_2) - \ln(R_1)) = \frac{\sigma R_1^2}{2\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)$

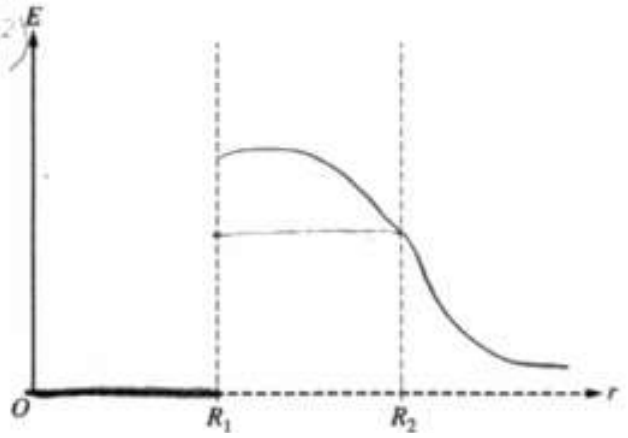


Figure 2

**PART B** $C = \frac{\kappa \varepsilon_0 A}{d}$ $A = 2\pi r l = 2\pi (R_2 - R_1) l$

$C = \frac{\kappa \varepsilon_0 \pi (R_2^2 - R_1^2) l}{R_2 - R_1}$



Go to Question 2 in Bluebook when you're done with this question.

## Question 1

**Note:** Student samples are quoted verbatim and may contain spelling and grammatical errors.

### Overview

**NEW for 2025:** The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

### Sample: 1A
### Score: 9

Part A (i) earned two out of three points. The first point (A1) was earned for including a multistep derivation that includes Gauss's law. The second point (A2) was earned for including a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$. The third point (A3) was not earned because the response uses the volume of the inner cylinder as opposed to its surface area to determine the enclosed charge. Part A (ii) earned both points. The first point (A4) was earned for including a substitution of the expression for $E$ from part A (i) into an equation that correctly relates $\Delta V$ and $E$. The second point (A5) was earned for including an attempt to solve an integral for $\Delta V$ that includes correct limits. Part A (iii) earned both points. The first point (A6) was earned for including a sketch of a graph that is zero for both $0 < r < R_1$ and $r > R_2$. The second point (A7) was earned for including a sketch of a graph that is decreasing and concave up for $R_1 < r < R_2$.

Part B earned all three points. The first point (B1) was earned for including a multistep derivation that includes the equation $C = Q/\Delta V$. The second point (B2) was earned for indicating that the capacitance with the dielectric material inserted is multiplied by a factor of $\kappa$. The third point (B3) was earned for including substitutions of both the total charge $Q$ and the potential difference $\Delta V$ that are consistent with part A.

### Sample: 1B
### Score: 6

Part A (i) earned two out of three points. The first point (A1) was earned for including a multistep derivation that includes Gauss's law. The second point (A2) was earned for including a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$. The third point (A3) was not earned because the response uses the volume of the inner cylinder, as opposed to its surface area, to determine the enclosed charge. Part A (ii) earned both points. The first point (A4) was earned for including a substitution of the expression for $E$ from part A (i) into an equation that correctly relates $\Delta V$ and $E$. The second point (A5) was earned for including an attempt to solve an integral for $\Delta V$ that includes correct limits. Part A (iii) earned both points. The first point (A6) was earned for including a sketch of a graph that is zero for both $0 < r < R_1$ and $r > R_2$. The second point (A7) was earned for including a sketch of a graph that is decreasing and concave up for $R_1 < r < R_2$.

Part B did not earn any of the three points. The first point (B1) was not earned because the response does not include a multistep derivation that includes the equation $C = Q/\Delta V$. The second point (B2) was not earned because the response does not indicate that the capacitance with the dielectric material inserted is multiplied by a factor of $\kappa$. Instead, the response states the equation for the capacitance of a parallel plate capacitor, as given on the reference sheet. The third point (B3) was not earned because the response does not include substitutions of both the total charge $Q$ and the potential difference $\Delta V$. Instead, it includes substitutions of the area of a parallel plate capacitor and the distance between the plates.

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## Question 1 (continued)

**Sample: 1C**
**Score: 3**

Part A (i) earned one out of three points. The first point (A1) was earned for including a multistep derivation that includes Gauss's law. The second point (A2) was not earned because the response does not include a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$. The third point (A3) was not earned because the response does not include a correct expression for the enclosed charge. Part A (ii) earned both points. The first point (A4) was earned for including a substitution of the expression for $E$ from part A (i) into an equation that correctly relates $\Delta V$ and $E$. The second point (A5) was earned for including an attempt to solve an integral for $\Delta V$ that includes correct limits. Part A (iii) did not earn either point. The first point (A6) was not earned because the response does not include a sketch of a graph that is zero for both $0 < r < R_1$ and $r > R_2$. The second point (A7) was not earned because the response does not include a sketch of a graph that is decreasing and concave up for $R_1 < r < R_2$.

Part B did not any of the three points. The first point (B1) was not earned because the response does not include a multistep derivation that includes the equation $C = Q/\Delta V$. The second point (B2) was not earned because the response does not indicate that the capacitance with the dielectric material inserted is multiplied by a factor of $\kappa$. Instead, the response states the equation for the capacitance of a parallel plate capacitor, as given on the reference sheet. The third point (B3) was not earned because the response does not include substitutions of both the total charge $Q$ and the potential difference $\Delta V$. Instead, it includes substitutions of the area of a parallel plate capacitor and the distance between the plates.

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